Precise study of ^{8}B beta decay

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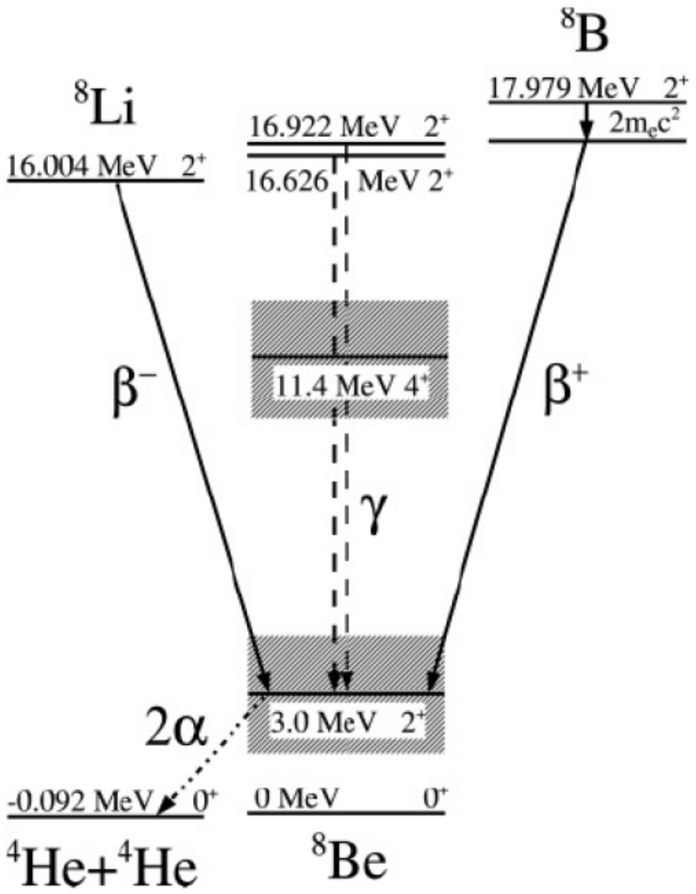
Motivation: decay via the continuum

- ^{8}B beta decay to 2^{+} states in ^{8}Be
- Unable to reproduce beta-delayed 2α spectrum nor α-α scattering cross section with 3 levels only

→ Add a 4th level

- at low excitation energy[1] : does not reproduce both α-α scattering and beta-delayed α spectra
- at higher excitation energy : physical meaning?

➔ Direct decay via the continuum or higher lying resonances? [2]



[1] F.C Barker, Aust. Journal of Physics **42**, 25 (1989)
[2] S. Hyldegaard, PhD thesis, Univ. Of Aarhus (2010)

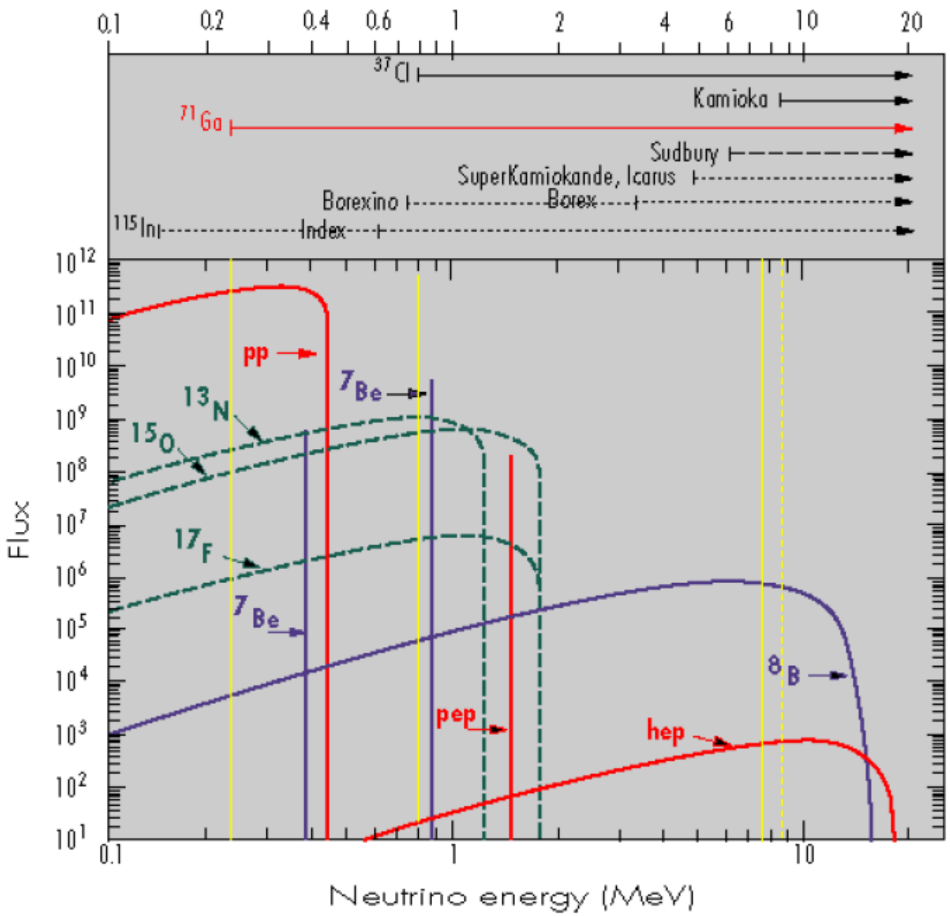
Motivation: solar neutrinos v.s. lab neutrinos

• Solar neutrino detectors
Super-Kamiokande, SNO, ICARUS
are sensitive to neutrinos from:

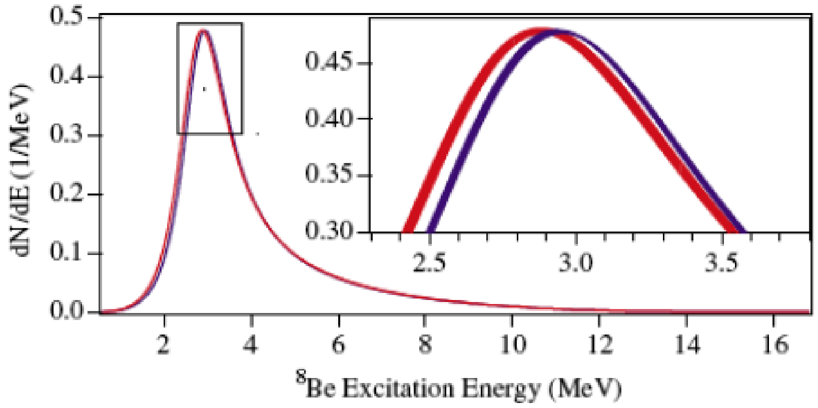
$$^{8}B \rightarrow {}^{8}Be + e^{+} + \nu_e$$

• The spectrum is depleted
and distorted by neutrino oscillations.
The distortion depends upon
the oscillation parameters

➔Need to know precisely the unperturbed ^{8}B ν_e energy spectrum!



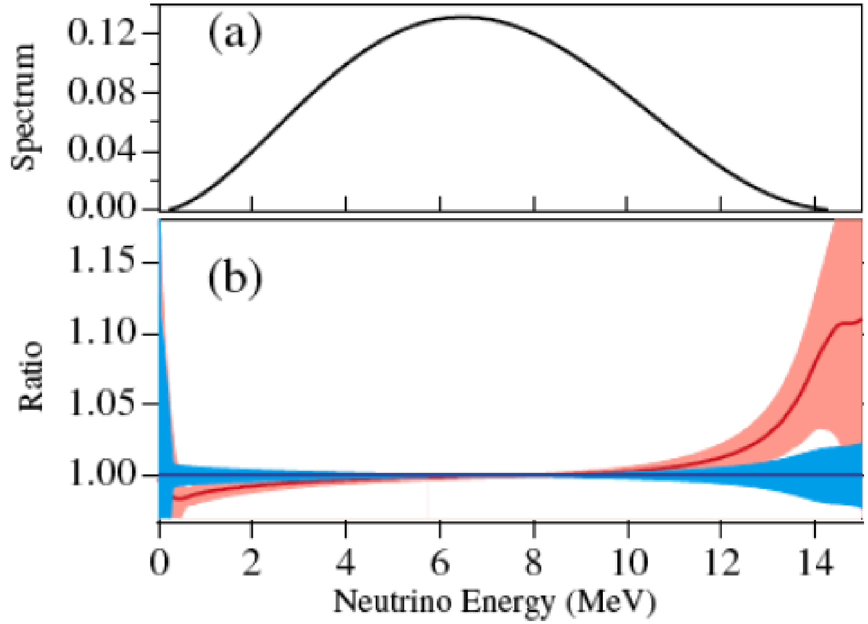
Motivation: state of the art



- 3 different measurements since 2000 :
  - -Ortiz : coincident α in C foil [(1)]
  - -Winter : coincident α in Si detector [(2)]
  - -Bhattacharya : single α in C foil[(3)]

- Large disagreement between Ortiz and Winter-Bhattacharya measurements

- All measurements have high detection threshold (>1MeV) → large uncertainties in the high energy part of the ν spectrum



(1) C.E. Ortiz *et al.*, Phys. Rev. Lett. **85**, 2909 (2000)
(2) W.T. Winter *et al.*, Phys. Rev. Lett. **91**, 252501 (2003)
(3) M. Bhattacharya *et al.*, Phys. Rev. C **73**, 055802 (2006)

The KVI experiment

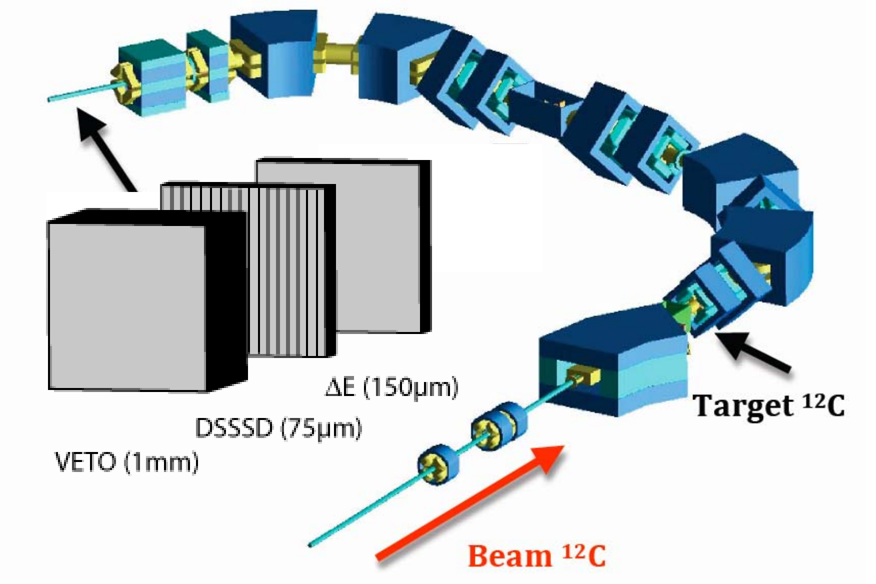
- Production of the ^{8}B beam : fragmentation of ^{12}C on ^{12}C

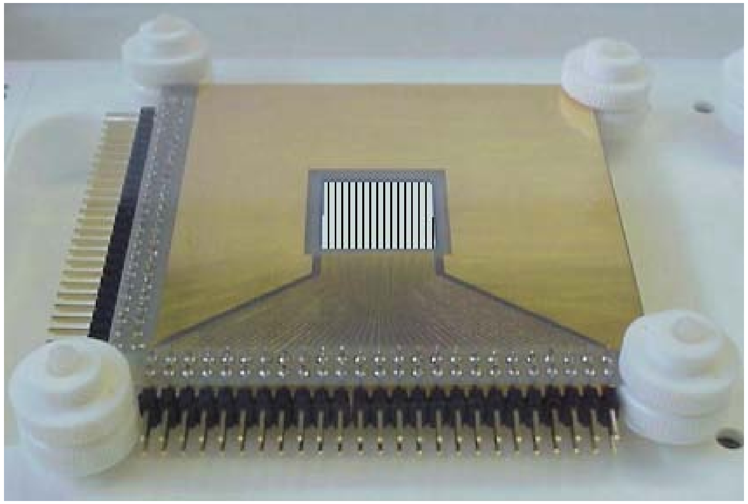
- Purification with the TRIμP spectrometer [(1)]

- Identification via ΔE-ToF & ΔE-E

- Implantation in a DSSSD [(2),(3)]
  - 16x16 mm², 78 μm thick
  - 48x48 strips → 2304 pixels
  - Cooled electronics

Low detection threshold
No dead layer effects

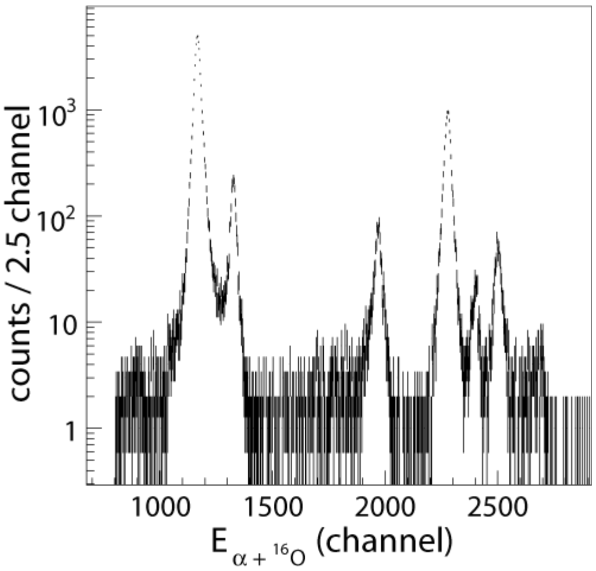




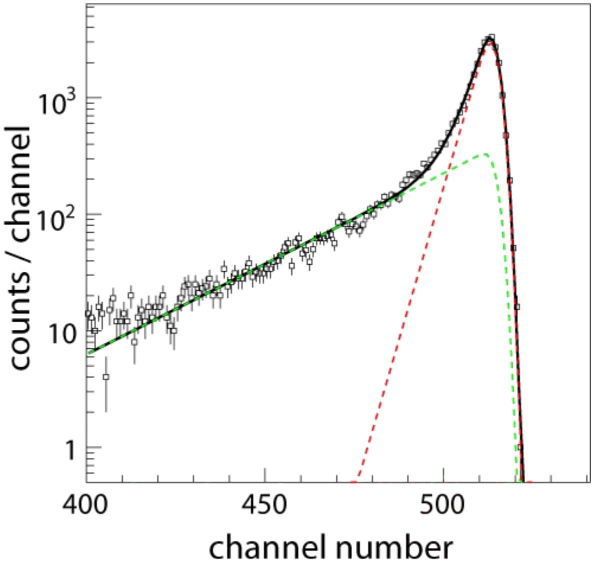
(1) G.P.A Berg. et al., NIM **A560**, 169 (2006)
(2) D. Smirnov et al., NIM **A547**, 480 (2005)
(3) J. Büscher et al., Nucl. Instr. and Meth. **B266**, 4652 (2008)

Calibrations: dead layer thickness & absolute calibration

- Measurement using implanted $^{20}Na \rightarrow ^{20}Ne^{*} \rightarrow ^{16}O + \alpha + e^{+}$
  - ➔ ^{16}O recoil pulse height defect:
    - → TRIM: $E_{ionisation}$ = 95-97% (~50 keV)
  - ➔ β-ν angular correlations & β summing:
    - → Full G4 simulation (~30 keV)
    - → Deconvolution



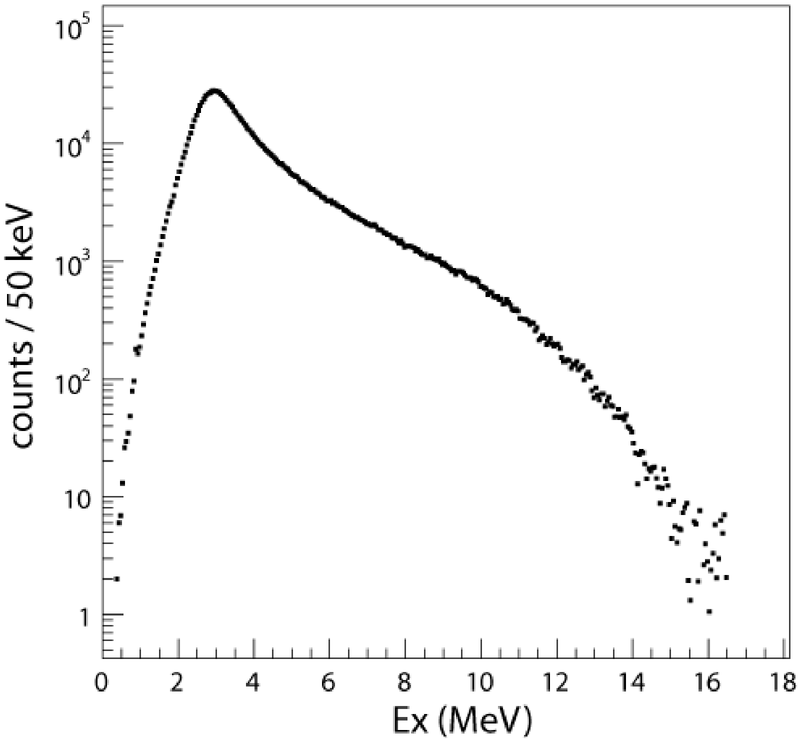
- Calibration with external α sources
  - ➔ Tailing due to the dead layer (~10 keV)



Effects of the order of the precision needed

Two-alpha spectrum measurement

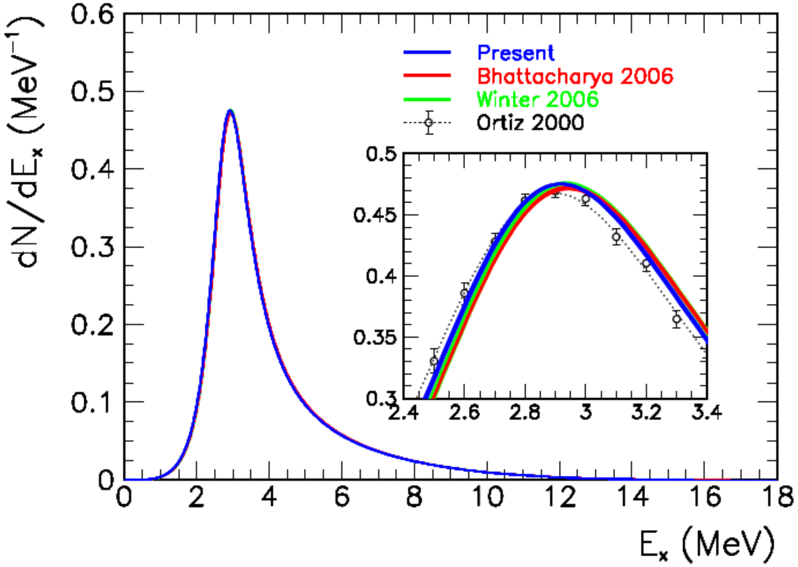
➔ 10^6 implantation-decay events



➔ Detection threshold = 400 keV

R-matrix preliminary results:

- Comments to previous analysis:
  - →16 MeV doublet not well treated
  - (Physical energy ≠ R-matrix energy)
- Spectrum maximum lies in between Ortiz and Winter's measurements.



O. Kirsebom, PhD Thesis, Univ. Of Aarhus (2010)

Lepton spectra extraction

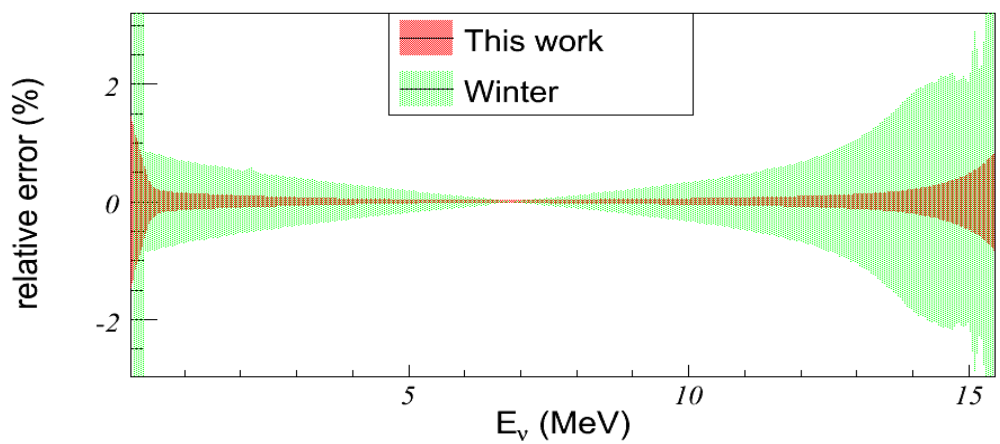
$$\left.\frac{dN}{dE_\beta}\right|_{Ex} \propto \underbrace{p_\beta E_\beta \left(E_0 - E_\beta\right)^2 \mathcal{F}\left(E_\beta\right)}_{\text{classic } \beta\text{-decay formula}} \times \underbrace{\left(1 + \frac{3E - E_0 - 3\vec{p}_\beta \cdot \vec{k}_\nu}{M}\right)}_{\text{recoil energy}} \times \underbrace{C\left(E_0, E_\beta\right)}_{\text{recoil order correction}} \times \underbrace{\mathcal{R}\left(E_0, E_\beta\right)}_{\text{radiative correction}}$$

Sources of error:

- Theoretical: error on recoil order correction dominates
- Calibration error: ~7 keV @ 3 MeV
- Error at high E_ν (lack of experimental data):

➔Previously: changing channel radius in the R-matrix fit

➔We extract the ν spectrum directly from the data



Collaborators

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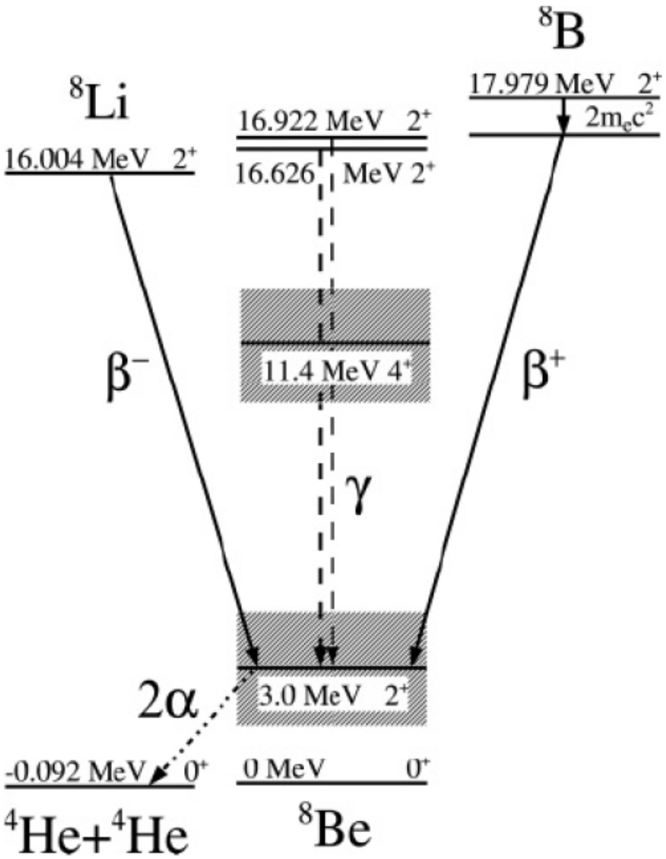
Data analysis: R-matrix analysis

- Fit of the distribution in the R-matrix framework
    - ➔ One channel – Many level approach
    - ➔ β decay selection rules :
      decay to 0^+ & 4^+ are secondly forbidden
    - ➔ Only 2^+ states are energetically allowed
    - ➔ 3 physical states + 1 background state



Data analysis: R-matrix analysis

$$\frac{dN}{dE_x} = \left(\frac{Nt_{1/2}}{6166}\right) f_\beta(E_x)(a^2(E_x) + c^2(E_x))$$

Fermi matrix element
$$a^2(E_x) = \frac{P(E_x)}{\pi} \times \left(\frac{\left|\sum_{j=1}^{4} \frac{\mathcal{M}_{Fj}\gamma_j}{\mathcal{E}_j - E_x}\right|^2}{\left|1 - (S(E_x) - B + iP(E_x))\sum_{j=1}^{4} \frac{\gamma_j^2}{\mathcal{E}_j - E_x}\right|^2} \right)$$

GT matrix element
$$c^2(E_x) = \frac{P(E_x)}{\pi} \times \left(\frac{\left|\sum_{j=1}^{4} \frac{\mathcal{M}_{\mathrm{GT}j}\gamma_j}{\mathcal{E}_j - E_x}\right|^2}{\left|1 - (S(E_x) - B + iP(E_x))\sum_{j=1}^{4} \frac{\gamma_j^2}{\mathcal{E}_j - E_x}\right|^2} \right)$$

Penetration factor
$$P(E_x) = \sqrt{\frac{2M_{2\alpha}E_x}{\hbar^2}} \frac{r_c}{F(r_c)^2 + G(r_c)^2}$$

Shift factor
$$S(E_x) = \sqrt{\frac{2M_{2\alpha}E_x}{\hbar^2}} \frac{r_c[F(r_c)F'(r_c) + G(r_c)G'(r_c)]}{F(r_c)^2 + G(r_c)^2}$$

Data analysis: R-matrix analysis

States parametrisation - 4x4 parameters:

2^+_1

- ε_1 free
- γ_1^2 free
- $\mathcal{M}_{GT1}$ free
- $\mathcal{M}_{F1}$ = 0 (SM.consideration)

2^+_4

- ε_4 = 37.0 (syst. – weak influence)
- γ_4^2 free
- $\mathcal{M}_{GT4}$ free
- $\mathcal{M}_{F4}$ = 0 (hypothesis)

2^+_2 - 2^+_3 : max. mixed isospin doublet

- ε_2 = 16.626 (exp)
- γ_2^2 = 10.96 keV (exp)
- $\mathcal{M}_{GT2} = \alpha\ \mathcal{M}_{GTA}$
- $\mathcal{M}_{F2} = \beta\ \mathcal{M}_{GTB}$

- ε_3 = 16.922 (exp)
- γ_3^2 = 7.42 keV (exp)
- $\mathcal{M}_{GT3} = \beta\ \mathcal{M}_{GTA}$
- $\mathcal{M}_{F3} = -\alpha\ \mathcal{M}_{GTB}$

With mixing parameters : $\alpha^2 = \Gamma_2/(\Gamma_2+\Gamma_3)$ and $\beta^2 = \Gamma_3/(\Gamma_2+\Gamma_3)$

and { $\mathcal{M}_{GTB} = \sqrt{2}$ (T=1 isospin eigenstate is the IAS of ^{8}LI & ^{8}B GS)
$\mathcal{M}_{GTA}$ free